Development of a conservation strategy for the Green and Golden Bell Frog *Litoria aurea* in the Illawarra Region of New South Wales

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ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* is recognized in New South Wales and nationally as a species in serious decline. We surveyed its current distribution and abundance in the Illawarra region of New South Wales in order to devise a regional conservation plan for this species, based on the objective of establishing at least three isolated, viable populations. The survey was conducted during 1997–1999 across 18 sites based on historic and current records of the species, and habitat suitability. Bell frogs were detected at eight sites, four of which were on public land. The maximum number of adult frogs varied from 11 to 78 across seven sites in Port Kembla, suggesting a population of >100 adult frogs. Breeding was poor at most sites during this study but a moderate number (*ca* 50) of juvenile frogs was observed at the BHP Steelworks site in January 1998 and at Coomaditchy Lagoon in February 1999.

Bell frogs were recorded previously at Shellharbour, where a large population occurred, and at Bulli. These areas are proposed as the other regional sites for bell frog conservation because they are well isolated (>10 km away) from Port Kembla. A small number of bell frogs was present at Bulli, while none was found at Shellharbour. The apparent stability of bell frogs in the Port Kembla area suggests that the presence of multiple breeding sites within a relatively small area (2.5 km radius) is very important and the establishment of viable populations in other areas should consider this situation as a model. This will require the creation of additional breeding sites at Bulli and Shellharbour, and may require translocation to Shellharbour if no occupied sites are found in the next few years. The presence of predatory fish at nine sites demonstrates the need for the conservation strategy to include activities that improve the quality of the habitat currently available to bell frogs.

INTRODUCTION

The Green and Golden Bell Frog *Litoria aurea* was once a common and conspicuous species throughout southeastern Australia where it was often associated with permanent water bodies (Barker *et al.* 1995; Gillespie 1996; White and Pyke 1996). It has suffered a marked decline in distribution and abundance during the last 20 years and was listed as endangered in New South Wales in 1992 (Lunney and Ayers 1993; Goldingay 1996; Osborne *et al.* 1996; White and Pyke 1996). It is currently listed as endangered under the New South Wales *Threatened Species Conservation Act 1995*. The populations within its more limited range in eastern Victoria appear to be stable (Gillespie 1996).

Approximately 43 sites with Green and Golden Bell Frogs remain in New South Wales but few populations appear to contain more than 20 individuals (White and Pyke 1996). This was partly the reason for this species being listed as vulnerable under the Australian *Endangered Species Protection Act 1992* in late 1997 (Commonwealth of Australia 1997). Only 22 populations are located outside the Sydney metropolitan area, with several occurring immediately south in the Illawarra region (White and Pyke 1996). A recent survey of the Port Kembla population in the Illawarra region confirmed that a relatively large population of bell frogs was present (van de Mortel and Goldingay 1998).

An important requirement of a conservation plan for any widespread but threatened species is to conserve populations throughout its geographic range (e.g., Murphy and Noon 1992). Such a strategy will ensure retention of genetic variability and local adaptation, but also provide security against all populations being exposed to adverse environmental conditions at once. From this perspective there is a clear need to devise regional conservation plans for threatened or endangered species.

Studies of the Green and Golden Bell Frog should now focus on the development of regional conservation strategies because sufficient aspects of this frog's ecology have been documented (see Pyke and Osborne 1996) and because any delay may have adverse consequences. An outline of a potential regional conservation strategy has been described previously (Goldingay 1996). Foremost among the management actions is the need for population monitoring, particularly of the largest populations, in order to clarify whether these populations are stable. Population monitoring has begun in Port Kembla using a simple counting technique to provide an index of population size (van de Mortel and Goldingay 1998).

The aims of this study were: i) to more fully document the distribution and relative abundance of bell frogs at sites throughout the Illawarra region of New South Wales, ii) to document the population monitoring at Port Kembla, and iii) to devise a conservation strategy for the species in this region.

METHODS

A survey for Green and Golden Bell Frogs was carried out at 18 sites in the Illawarra region between January 1997 and March 1999 (Table 1). The sites selected included historically occupied sites, sites that were known to be currently occupied, and a widespread set of sites containing what was considered to be suitable habitat. The latter was defined by the presence of freshwater ponds, dams and lagoons with emergent aquatic vegetation, and which were consistent with descriptions provided by Pyke and White (1996). Many sites with suitable habitat were included to assess whether undiscovered populations may be present, but also to provide the opportunity to identify sites that may later provide options for translocation. The distribution of sites extended from Bulli in the north to Shellharbour in the south (Fig. 1). Bell frogs were abundant at two of the sites in Shellharbour prior to 1990 (Table 1). At one of these (Killalea Lagoon), three bell frogs were detected in January 1994 (A. White, pers. comm.). Bell frogs occurred in the Tongarra Creek wetland in the 1980s, which is located 1.5 km from the other two Shellharbour survey sites (Chafer 1997). It is likely that other populations occur in the Illawarra. The amount of field work required across the 18 survey sites did not permit investigation of potential habitat to the north-west or south-west of Lake Illawarra.

Thirteen sites were visited at least five times between January and mid-April 1997 (see Table 1). All sites were surveyed within a 3-day period to reduce the influence that weather conditions may have on the detection of bell frogs. These sites were visited both day and night. Two sites (Coomaditchy Lagoon, Gloucester Boulevarde) with bell frogs were visited more frequently in order to collect abundance data, to examine breeding and also to demonstrate that weather conditions were suitable for detecting bell frogs at that particular time. Diurnal and nocturnal surveys did not follow any prescribed timing but we tried to conduct surveys during warm and wet periods. All Port Kembla sites except the Golf Course were also visited in January and November 1998, and January and February 1999. Another two sites (CB quarry, Bellambi Colliery) were only visited late in the survey following reports that bell frogs were present

Table 1. Characteristics of sites surveyed in the Illawarra for Green and Golden Bell Frogs. Breeding habitat shows the area (ha) of the water body. BF = bell frogs recorded within 12 months before 1997, R = record of bell frogs in last 10 years. Tenure = current ownership of site (Pr = private; LC = local council; S = State government). Fish shows the number of plague minnows per 30 litres of water sampled or not quantified (F). Diurnal and Nocturnal show the number of surveys at a site in 1997 (1998:1999).

Site (habitat type)	Breeding habitat	Tenure	Fish	Diurnal	Nocturnal
Bulli-Bellambie Area					
1. Bellambi Creek (Dam)	0.3	Pr	2.5	5	3
2. Rixon's Pass (Dam)	0.3	Pr	F	(2:1)	(2:1)
3. Bellambi Colliery (Dam)	0.2	Pr		(2:1)	(2:1)
4. Bellambi Lagoon (Lagoon)	1.4	LC	7.0	5	3
Wollongong Area					
5. Stuarts Park (Dam)	0.3	LC	8.0	4	3
6. Wollongong Golf Course (Dam)	0.2	Pr	13.0	5	3
Port Kembla Area					
7. BHP Steelworks (Dammed creek)	0.1 (BF)	Pr		4 (2:1)	3 (2:1)
8. CB quarry (Sediment pond and channels)	0.2 (BF)	Pr		1 (3:1)	
9. Gloucester Boulevarde (Ephemeral ponds)	0.1 (BF)	Pr		12 (1:0)	12 (1:2)
10. Boiler's Point (Pond)	0.1	LC		1 (3:2)	3 (4:2)
11. Coomaditchy Lagoon (Lagoon)	2.8 (BF)	LC	8.0	15 (3:1)	18 (9:3)
12. South Pond (Pond)	0.3	LC		(1:1)	(1:3)
13. Korrongulla Wetland (Mined ponds)	1.8 (BF)	S	3.0	6 (2:2)	5 (2:2)
14. Port Kembla Golf Course (Dam)	1.1	Pr	10.0	4	3
Shellharbour Area					
15. Blackbutt Estate (Dam)	0.7	LC		5	4
16. Shellharbour Estate (Dam)	0.3	LC		5	4
17. Shellharbour Golf Course (Dam)	0.5 (R)	Pr	2.5	4	3
18. Killalea State Recreation Area (Lagoon)	4.5 (R)	S		5 (1:2)	3 (0:1)

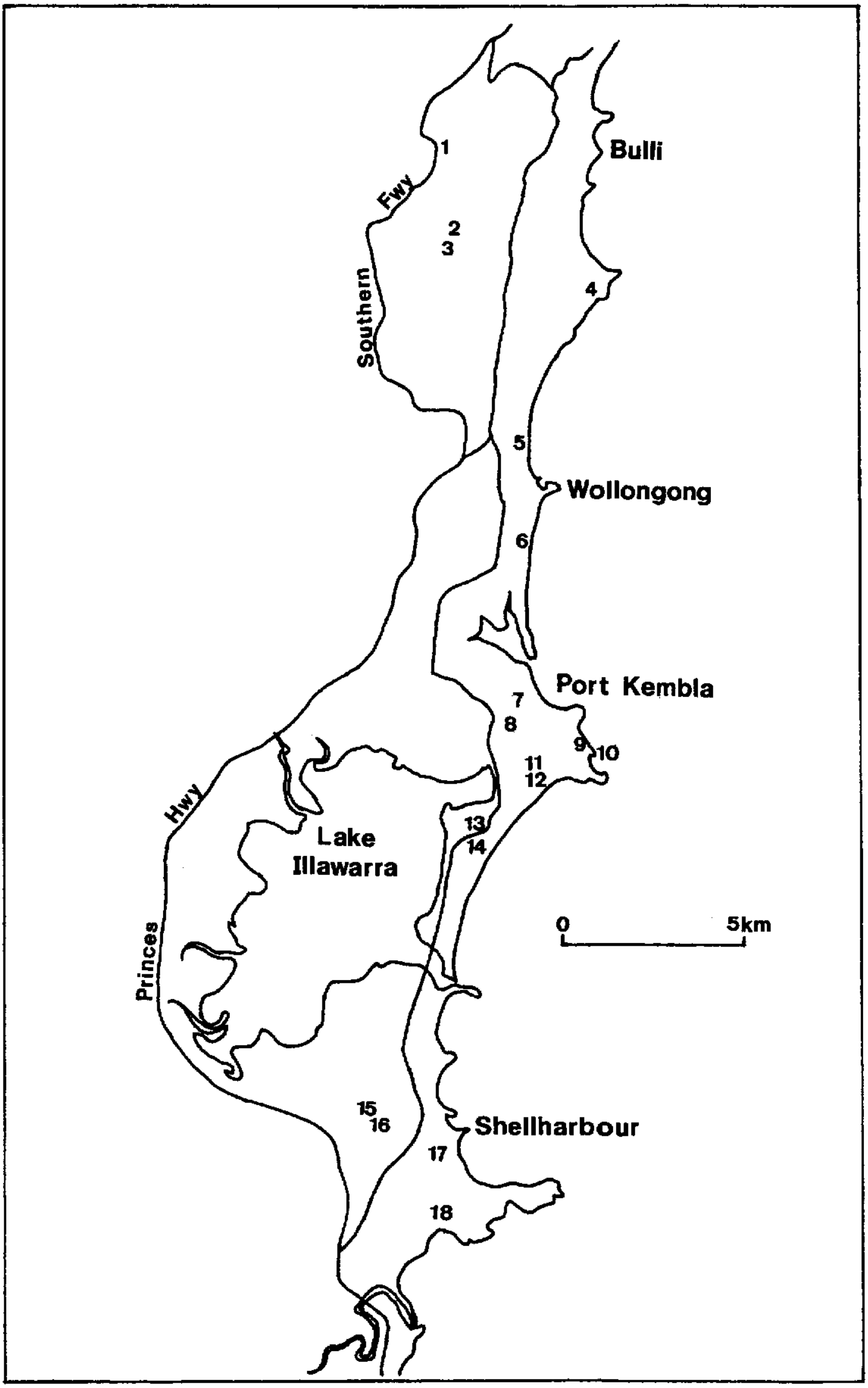

Figure 1. Location of survey sites in the Illawarra region. Vertical lines west of the coastline are roads. See Table 1 for numbered sites.

(A. White, pers. comm.). One was surveyed in November 1997 and January 1998 while both were surveyed in March 1998, November 1998 and January 1999 (Table 1). South Pond was surveyed several times after locating it in November 1998. Sites were surveyed several times between November and March each summer, allowing a maximum count within a 2-month period to indicate the relative abundance of bell frogs at a site.

Diurnal surveys consisted of active searches to locate basking bell frogs. These surveys were regarded as acceptable given the diurnal basking behaviour of bell frogs (Cogger 1992, pers. obs.). Nocturnal searches involved illuminating areas of aquatic vegetation and the edge of the waterbody with a 50 watt spotlight following the procedure of van de Mortel and Goldingay (1998). Call imitation was also used to elicit calls from bell frogs during site visits. This is a commonly used method for detecting bell frogs (Clancy 1996; Osborne and McElhinney 1996; van de Mortel and Goldingay 1998). A minimum of 20 minutes was spent at a site when no frogs were recorded. Counts of adults and juvenile bell frogs occurred concurrently at all but one site. The defintion of juvenile includes metamorphlings and subadults (<5 cm snout-vent). At Coomaditchy Lagoon, the time required to search the entire lagoon perimeter (*ca* 2 h) required counts of adult and juveniles to occur on separate nights.

In June 1997, a small pond (8 × 10 m) was constructed 200 m south of the Gloucester Boulevarde site in Port Kembla as part of the development of a management plan for the bell frogs at Coomaditchy Lagoon (van de Mortel *et al.* 1998). This pond was surveyed between November 1997 and March 1999. In November 1998, frogs were captured and held in plastic bags until the count was completed to avoid double counting.

The presence of bell frogs was also assessed by searching for their tadpoles (which are confined to breeding sites for an extended period) with a small dip net made from fine mesh. Heyer *et al.* (1994) advocated the combination of survey techniques to increase the accuracy of short-term surveys. Tadpoles were identified by using details provided by Daly (1995). Where there was any doubt, tadpoles were reared to metamorphosis. Tadpole sampling was conducted at each site during all diurnal visits and further searches were conducted at night when tadpoles are easier to detect with the aid of a spotlight.

Surveys were conducted at all sites to document the presence and density of the plague minnow *Gambusia holbrooki*, which has been implicated in the decline of the Green and Golden Bell Frog in New South Wales (Morgan and Buttemer 1996; Pyke and White 1996). A dip-net (diameter 35 cm) was scooped through approximately 30 litres of water and the number of fish captured was recorded. This was repeated three times in adjacent water columns along the edge of all water bodies. Fish surveys were conducted during the day and at night and averaged.

The aquatic habitat at Coomaditchy Lagoon, Gloucester Boulevarde, BHP Steelworks and Korrongulla Wetland has been described previously (see van de Mortel and Goldingay 1998). All Illawarra sites contained cumbungi *Typha orientalis*, which was dominant at most sites. At Bellambie Creek, tall spikerush *Eleocharis sphacelata* was dominant, while it was co-dominant at Coomaditchy Lagoon and Shellharbour Estate. Bellambie Lagoon was also dominated by the common reed *Phragmites australis*. At South Pond (Fig. 2), jointed rush

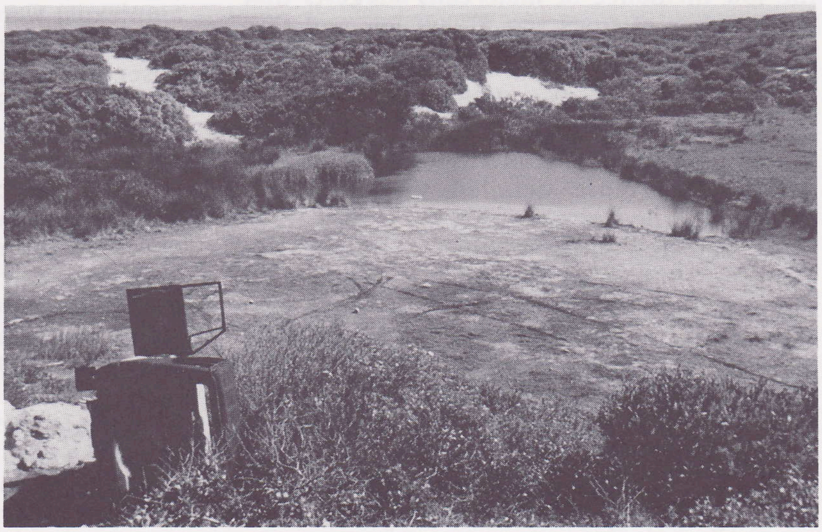

Figure 2. Habitat of the Green and Golden Bell Frog at South Pond in January 1999. The pond extended over the bare ground in November 1998.

Juncus articulatus dominated the vegetated banks and there was a large patch of rice sedge *Cyperus difformis*. The main exception in habitat was the dam at BHP which was dominated by the exotics lantana *Lantana camara* and bitou bush *Chrysanthemoides moniliferum*. The main emergent plants from the edge of the dam were kikuyu *Pennisetum clandestinum* and slender knotweed *Persicaria decipiens*.

RESULTS

Distribution and habitat of occupied sites

Green and Golden Bell Frogs were found at 8 of the 18 sites surveyed. Seven occupied sites were located within the Port Kembla area, while one was in the northern Illawarra near Bulli. This represents all sites known to be occupied by bell frogs in the 12 months prior to this survey (Table 1) as well as three new sites (Boilers Point, South Pond, Bellambie Colliery).

Repeated visits to occupied sites in 1997 allowed detectability to be examined. Bell frogs were detected during every visit to the BHP steelworks, during 89% of visits to Gloucester Boulevarde, and during 70% of visits to Coomaditchy Lagoon. This occurred regardless of the prevailing weather. Overall, there was a greater frequency of detection at night (92% of visits) compared to during the day (68%) at these sites. In contrast, bell frogs were detected during one nocturnal and one diurnal survey (33% of all surveys) at Korrongulla Wetland. This site was surveyed again in January 1998 when calls were elicited from 11 male bell frogs during the day but none were detected at night. The low detection rate at this site partly reflects an inability to search the site effectively due to the steep banks of most of the ponds, which makes viewing the fringing cumbungi hazardous, and due to the dense cumbungi surrounding the ephemeral pond. However, the low incidence of male calls suggests that the number of frogs was always low and that the site is marginal for breeding.

At CB quarry in Port Kembla, 11 subadult bell frogs were detected during a brief diurnal survey in November 1997. Access constraints prevented a more detailed survey of this privately-owned site at this time. No frogs were detected during diurnal surveys in January 1998 when all surface water had disappeared from the site. No frogs were seen during a further diurnal survey in March 1998 when a sediment pond (20 × 20 m) had a 20 cm depth of water, but three were observed in January 1999. Several residents adjoining this site have frogs using garden ponds, and in one instance a disused swimming pool is used regularly by 10–20 adult frogs.

Adult bell frogs were detected at the new breeding pond (Boilers Point) on Gloucester Boulevarde during each nocturnal visit between November 1997 and February 1999 and at South Pond during each visit in November 1998, and January and February 1999.

These results suggest that an equivalent survey effort at other sites should detect bell frogs if they were present. However, no bell frogs were found at the Shellharbour sites where frogs were abundant prior to 1990. Six male bell frogs were detected at a pond in the Bellambi Colliery near Bulli in December 1997 (A. White, pers. comm.). A survey of this site in March 1998 detected one (subadult) bell frog during the day but none at night.

The size and structure of the aquatic habitat varied across sites (Table 1). The only locations where natural habitat occurred were those sites where coastal lagoons were present. Other habitat areas consisted of dams and retention ponds. Of those where bell frogs occurred, the dam at the Bellambie Colliery and the ponds left after sandmining at Korrongulla contained very steep banks. Plague minnows were present at eight sites, including two with bell frogs (Table 1). The density varied from 2.5 to 13 fish per 30 L, with Coomaditchy Lagoon containing one of the highest densities.

Bell frog abundance

The abundance of frogs varied considerably among the sites; two sites (Coomaditchy Lagoon, BHP steelworks) had a maximum count of more than 60 adult frogs (Fig. 3). Two other sites (Gloucester Boulevarde, Korrongulla) had maxima of 26 and 11 adult frogs (Fig. 4). A fifth site (CB quarry) could not be surveyed at night but 11 subadults were detected during a brief diurnal survey. Eight adult bell frogs (one pair attempting amplexus) were detected at the Boilers Point pond in November 1997, while 20 were observed there in November 1998 (Fig. 5a). There were 18 adult frogs detected at South Pond in January 1999 (Fig. 5b).

Considerable variation in bell frog numbers was noted at all sites, with the largest counts observed under various weather conditions. The lowest counts were mostly recorded during extended dry periods. The maximum count at Coomaditchy Lagoon occurred in November 1996 (Fig. 3a) during dry weather but counts were abandoned on five nights in January 1998 due to limited frog activity during a prolonged dry period when the water level in the lagoon had dropped to the lowest level seen. The maximum count

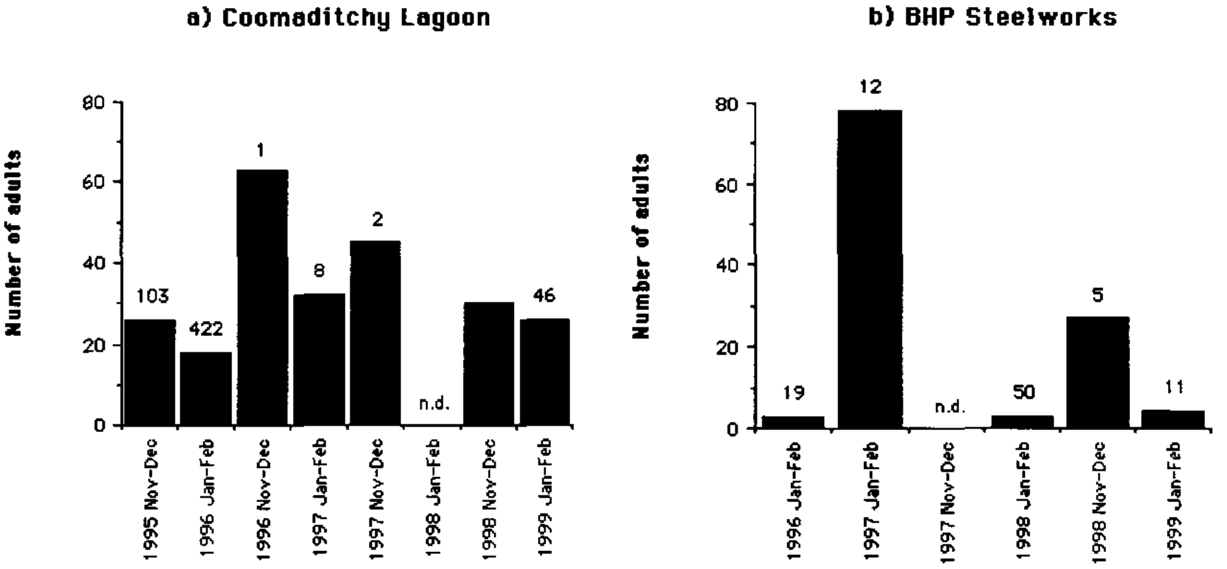

Figure 3. Maximum number of adult bell frogs detected for 2-month periods at a) Coomaditchy Lagoon, b) BHP steelworks. Numbers above bars are the maximum number of juvenile frogs detected. n.d. = no data. Data for 1994–1996 are from van de Mortel and Goldingay (1998).

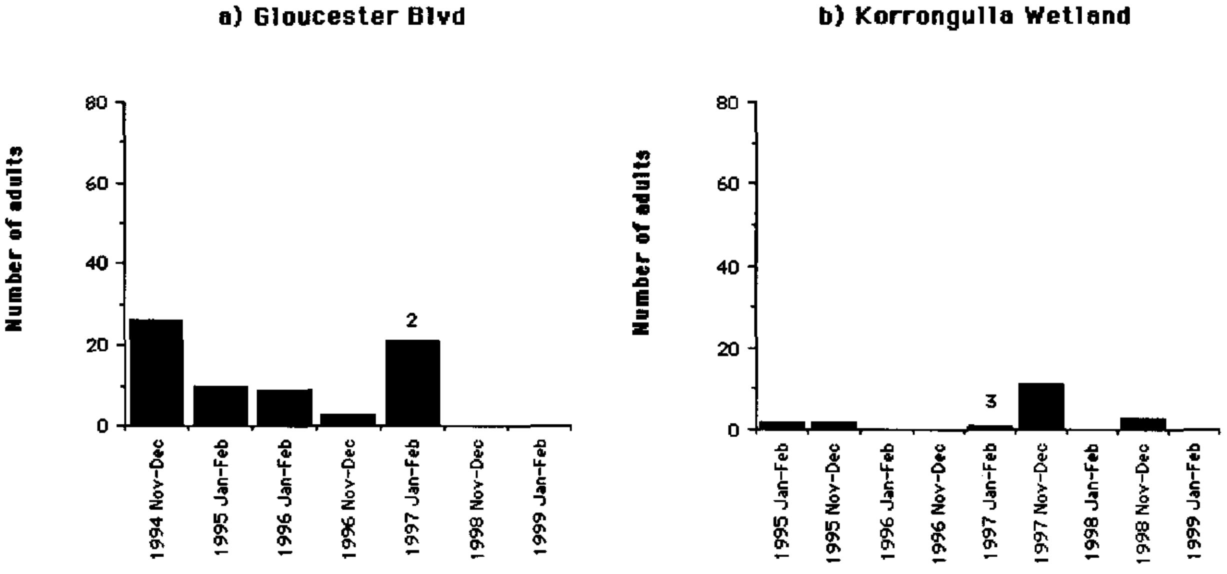

Figure 4. Maximum number of bell frogs detected at a) Gloucester Boulevard, b) Korrongulla Wetland. See Figure 3 for explanation.

at the BHP Steelworks was during wet weather in February 1997 (Fig. 3b). This variation has required repeat visits to a site in order to adequately assess relative abundance. The data obtained at Coomaditchy Lagoon over four spring-summers suggest that bell frogs are more active (and calling spontaneously) in November and that numbers decline in the January-February period (Fig. 3a). Frequent rain in January 1999 coincided with only a slight decrease in the number detected compared to November 1998.

Substantial variation was evident between the diurnal and nocturnal counts, with a greater number of frogs counted almost invariably at night. This appears to reflect the movement by frogs into diurnal shelter sites with only a small proportion seen basking. Furthermore, surveys also depend on male calling behaviour which may be frequent at night. Korrongulla was an exception to this with the largest count occurring in the day when frogs responded to a simulated call, but none were seen or could be prompted to call that night.

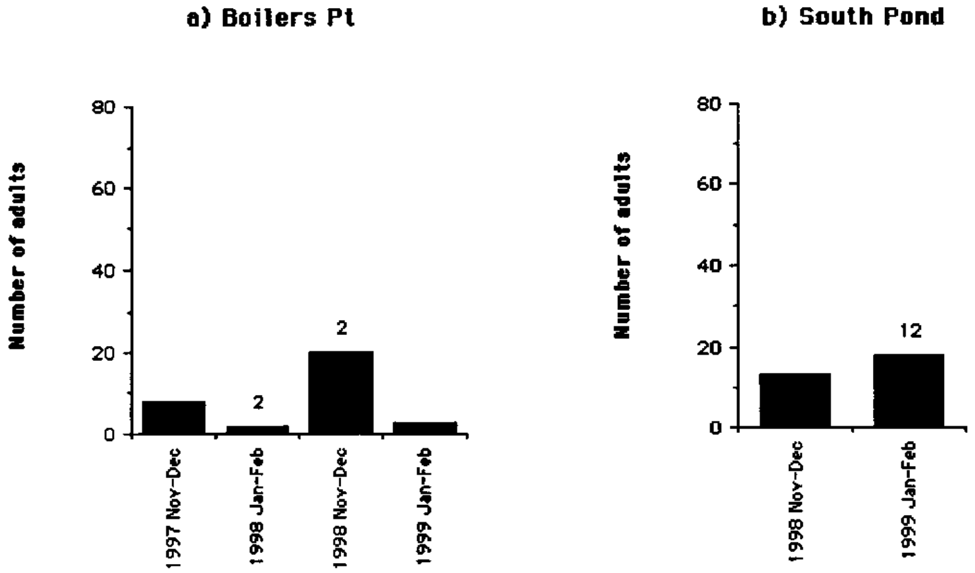

Figure 5. Maximum number of bell frogs detected at a) Boilers Point, b) South Pond. See Figure 3 for explanation.

Breeding frequency

The detection of juvenile bell frogs can be used to indicate breeding intensity at a site and provides some insight into the value that a particular breeding site may have for the population. In this study, the number of juveniles varied across the four sites surveyed over the longest period (Figs 3 and 4). Coomaditchy Lagoon appears to provide the most important breeding site. Large numbers of juveniles were detected there in January 1996 and a moderate number in February 1999, following two poor breeding seasons (Fig. 3a) when the water level in the lagoon dropped to very low levels.

Monthly rainfall data for Wollongong University were obtained from the Bureau of Meteorology for the period September 1995-February 1999. Data were collated for 4-month periods each year, to compare rainfall in the period September-December with the maximum number of juveniles seen at Coomaditchy Lagoon in the following January-February period (Fig. 6). This suggests

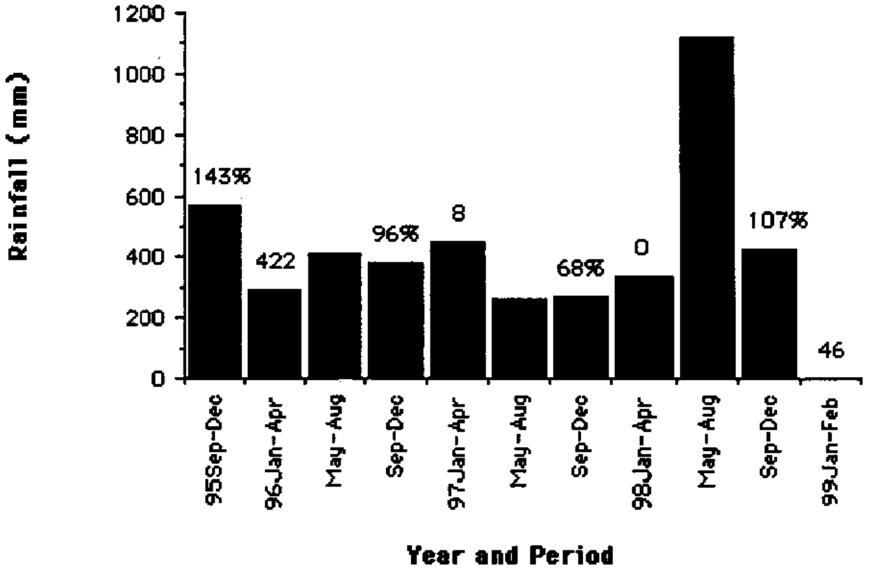

Figure 6. Rainfall recorded at the University of Wollongong for 4-month periods from September 1995 to December 1998. Values above bars show the % of average rainfall for each September-December period and the maximum count of juvenile bell frogs at Coomaditchy Lagoon in each January-February.

a close relationship between the amount of rainfall in the September-December period relative to a 28 year average for that period, and the number of juveniles seen. Higher than average rainfall during the breeding period may mediate avoidance of fish predation.

The BHP Steelworks dam appears to have bell frog tadpoles present over a longer period than any other site and some juveniles were observed during most visits (Fig. 3b). This site had a successful breeding year in January 1998 when no juveniles were detected at other sites. In contrast, breeding at Gloucester Boulevarde and Korrongulla appears to be very limited (Fig. 4).

The discovery of 11 subadults at the CB quarry site in November 1997 suggests that these frogs had metamorphosed the previous autumn. It is assumed that these metamorphlings resulted from breeding at this site. Three juveniles were seen there during the day in January 1999. Spawning occurred in the pool on an adjoining residential property which produced several hundred tadpoles. Approximately 50 large bell frog tadpoles were present at the new pond on Gloucester Boulevarde in February 1998. In March 1998, seven juveniles were seen during the day on cumbungi growing in this pond. The water dropped to a low level in early 1999 but bell frog tadpoles were present in February. In late March, 12 juveniles and >30 tadpoles were observed at night. At South Pond, 12 juveniles were observed at night in January and February 1999, suggesting that moderate breeding occurred at this site.

DISCUSSION

Distribution and abundance of bell frogs in the Illawarra

Determining the status of bell frogs across a region is fundamental to devising a conservation strategy. A starting point for such an endeavour is the identification of appropriate sites for survey. Surveys of these sites should be repeated and should target all stages of the frog life cycle. Questions then arise about the timing and frequency of appropriate surveys. This study has demonstrated that nocturnal surveys were more effective than diurnal surveys but surveys at both times can be complementary. Searching during a variety of weather conditions, particularly wet weather if sites contain only small areas of breeding habitat (van de Mortel and Goldingay 1998), will increase survey effectiveness. The time of the year may also influence frog activity. At Coomaditchy Lagoon, more adult frogs were detected during four November-December periods compared to the following January-February period. However, there was no consistent pattern at other sites. In contrast, juvenile frogs appeared to be more abundant in January-February than at other times. Detecting juveniles is important to provide an index of breeding success. We recommend a minimum of two surveys during each of these 2-month periods each year to be able to properly index adult abundance and breeding success.

Within Port Kembla, bell frogs were detected at seven sites. Coomaditchy Lagoon and the BHP site had aggregations of more than 60 adult frogs, while three other sites had about 20 adult frogs. One of the latter sites appears to now offer only marginal habitat due to changes in its drainage but a pond constructed nearby may support as many frogs. These observations suggest that the overall population size in Port Kembla is about 100–150 adult frogs.

One significant feature of the Port Kembla sites is their close proximity to each other (Fig. 1). All breeding sites are within a 2.5 km radius, and are separated by many roads and extensive residential development. We have observed adult bell frogs sheltering in residential gardens located 200–300 m from a breeding site. Adult frogs have been found dead on the road adjacent to Coomaditchy Lagoon and an adult frog was observed at night crossing the road adjacent to the BHP site (T. van de Mortel, pers. comm.). Adult frogs were attracted to the Boilers Point pond (200 m from the Gloucester Boulevarde breeding site) in the spring following its construction. These observations suggest that adult frogs within the area are highly mobile and may move among the breeding sites. This is also suggested by the limited knowledge of the movement behaviour of this species (Murphy 1995; White and Pyke 1996; A. White, pers. comm.). A study in which frogs are PIT tagged (see Christy 1996) has been initiated to investigate their movement patterns at these sites. A juvenile frog was found on a road one night approximately 700 m from the nearest breeding site. This indicates that a study of juvenile dispersal is also needed to understand the population ecology of this species.

Shellharbour and Bulli are two other areas where bell frogs have been detected since 1990. In Shellharbour, we failed to detect bell frogs at two formerly occupied sites, including one (Killalea) where three frogs were heard calling in January 1994 (A. White, pers. comm.). This site contains extensive habitat which has been surveyed under conditions suitable for bell frog activity at other sites. The population in Shellharbour may have numbered close to 100 prior to 1990 (C. Chafer, pers. comm.). Further surveys should be conducted over two more breeding seasons before it can be concluded that bell frogs have disappeared from Shellharbour. It appears the population has undergone a rapid decline due to unknown factors.

Six calling bell frogs were detected at a pond within a colliery near Bulli in late 1997 (A. White, pers. comm.). A subadult bell frog was detected there in March 1998 but none was detected in November 1998 or January 1999. We failed to detect bell frogs at one site 1 km north and at two survey sites located approximately 3 km east and north of the occupied site. However, three bell frogs were detected at a disused brickworks approximately 2 km north-east of the colliery in January 1999 (K. Mills, pers. com.). These observations suggest a very small population is present in the area. White and Pyke (1996) reported three historic locations in this area (Bulli, Thirroul, Woonona) indicating that the area has been an important location for the species over a long period.

Clearly, many other areas of potential habitat occur in the Illawarra (see Chafer 1997) that were not surveyed. This study has employed a successful survey methodology that was tested across a broad range of sites with varying densities of bell frogs. It should now be used to identify any remaining populations of bell frogs in the Illawarra.

Bell frog breeding

Several conclusions may be drawn from the observations of the number of juvenile frogs seen at a site, which is used as an index of breeding success. Firstly, that breeding success can vary substantially from one year to another. Secondly, that Coomaditchy Lagoon is the most important breeding site followed by the BHP Steelworks when viewed over several years. Thirdly, that the Korrongulla and Gloucester Boulevarde sites appear to be consistently poor breeding sites.

The variation in breeding success among sites in a given year highlights the need for several breeding sites for a population. Moderate breeding occurred at the Steelworks in January 1998 when no breeding was apparent at Coomaditchy. Breeding at Coomaditchy appears to be strongly influenced by above average rainfall during September-December. Observations suggest that the size of the water body and the area of fringing vegetation may influence the intensity of breeding. The largest breeding event observed was that at Coomaditchy Lagoon which provides the largest breeding site in Port Kembla. The increase in the number of adults the following November suggests that frogs were recruited to the adult population from that breeding event.

Some sites may continue to offer poor breeding opportunities for frogs. Low breeding rates at Gloucester Boulevarde may be attributed to the ephemeral nature of the breeding sites. Although frogs often spawned at this site, the water bodies do not persist for long enough for tadpoles to complete development. A new pond constructed 200 m from the site was quickly occupied by adult frogs and allowed successful breeding. At the Korrongulla site, very high densities of fish and steep pond banks may contribute to poor breeding. The construction of small shallow ponds at each of these sites may help improve breeding.

Threatening factors

Identifying the factors involved in the decline of the Green and Golden Bell Frog in the Illawarra region is an integral part of preparing a conservation strategy. Two factors that appear to have influenced the current distribution of bell frogs are the loss or modification of habitat and the introduction of the plague minnow *Gambusia holbrooki*. Goodrick (1970) stated that up to 60% of New South Wales wetlands had been extensively modified or reclaimed by 1969. Wetlands in the Illawarra region have been substantially altered in the past to allow for residential development and the expansion of industry (Chafer 1997). Much of the BHP industrial site in Wollongong was formerly a wetland. Coomaditchy Lagoon has been partly modified while Korrongulla Wetland has been extensively modified by sand-mining (Chafer 1997). Each of these sites abut residential development and experience on-going disturbance. Freshwater wetland areas in Shellharbour have also been greatly modified while very few remain in the Bulli area.

The plague minnow is found throughout the area where the bell frog has suffered a decline in distribution (White and Pyke 1996). This fish has been strongly implicated in the decline of the Green and Golden Bell Frog (Morgan and Buttemer 1996; Pyke and White 1996) and has continued to increase in distribution and abundance since its initial release in 1925 (Myers 1965). This fish is now widespread throughout the Illawarra region but was absent from nine sites surveyed during this study (Table 1). However, it is abundant at Coomaditchy Lagoon where bell frogs still breed. The abundance of aquatic vegetation at Coomaditchy is believed to ameliorate the impact of fish predation (van de Mortel and Goldingay 1998). The influence of above average rainfall during September-December on breeding intensity suggests that successful breeding is also facilitated by the water level in the lagoon spilling into the thickly vegetated perimeter of the lagoon. The plague minnow poses an on-going management problem because it is widespread and often reinvades areas where it has been eliminated. The presence of this fish at Korrongulla is likely to limit breeding success.

A conservation strategy for bell frogs in the Illawarra region

A broad conservation strategy that has been advocated for regional conservation of bell frogs is to designate at least three isolated, viable populations (Goldingay 1996). Thus, we must determine when a population is isolated, when it is viable, and how to maintain it. The latter requires identification of factors that may affect the suitability of habitat at a site.

How do we know when a population is really isolated from another? Given the high mobility of the bell frog, further research is needed to say with any confidence when populations are isolated. However, a conservation plan should be cautious when being developed in the absence of accurate ecological information. Most frog breeding sites within the Port Kembla area appear to be within dispersal distance of each other and should be treated as part of a single population (see above). This includes Korrongulla although this site is somewhat isolated from the other sites. Populations which are clearly isolated (>10 km from others) occurred at Bulli and Shellharbour. There are several historic records from each area but the number of frogs detected was low at Bulli and we could not detect any at Shellharbour. Despite this, these areas and Port Kembla offer the only opportunity at present for three isolated areas that may be used to conserve the bell frog within the Illawarra region (Table 2). These sites may have formed a metapopulation (i.e., populations linked by dispersal) historically but the extent of urban development between these sites today would make occasional dispersal very unlikely.

The discovery of any further bell frog sites in the Illawarra region should be treated and managed as new regional locations if located >5 km from the three areas above. Such sites may replace Shellharbour and Bulli as part of the three core populations for conservation if bell frogs are more abundant at any new sites. This should lead to a change in management emphasis but not to abandoning Shellharbour and Bulli which were historically important areas for bell frogs and because conserving more than three populations will enhance long-term persistence in the region.

Translocation of frogs to Shellharbour should be considered if no frogs are found there over the next two breeding seasons. Killalea Lagoon is the preferred location due to its very large size (4.5 ha) and public ownership, but Blackbutt Estate is also quite suitable due to its moderate size, good habitat and absence of fish. The construction of new ponds may be required (see below).

How do we define a viable population? This cannot be done with any confidence at present. However, several observations provide guidance here. It has been shown empirically

Table 2. A regional conservation strategy for the Green and Golden Bell Frog in the Illawarra. Regional actions are those that enhance or provide insight into regional conservation. Local actions are those concerned with enhancing persistence at individual sites. Locations: CL = Coomaditchy Lagoon, GB = Gloucester Boulevarde, BP = Boilers Point, BHP = BHP Steelworks, SP = South Pond, CB = CB quarry, KW = Korrongulla Wetland, BC = Bellambi Colliery, KL = Killalea Lagoon.

Management Actions	Location of implementation
Regional Actions	
1. Identify three separate populations	Bulli, Port Kembla, Shellharbour
2. Assess population status	BC, KL
3. Translocation if frogs are absent	Shellharbour
4. Study adult frog movements	Port Kembla
5. Study juvenile frog dispersal	Port Kembla
6. Study effects of water contamination on frogs	Port Kembla
Local Actions	
1. Provide breeding ponds	GB, BHP, KW, BC, KL
2. Improve breeding pond water quality	Most Port Kembla sites
3. Modify existing pond	GB, CB, KW, BC
4. Annual monitoring	CL, BHP, BP, SP, CB, BC, KL
5. Permanent tagging to assess population size	CL, BP, BHP, KW
6. Community involvement	CL, GB, KW
7. Assess road mortality	CL, GB

that larger populations have greater viability than smaller ones (Berger 1990). White and Pyke (1996) observed that the bell frog population at Eastlakes (Sydney metropolitan area) was largest when it occupied the greatest number of waterbodies. It declined and disappeared as the number of occupied waterbodies declined. The large bell frog populations at Homebush and Kurnell (also in the Sydney area) are also characterized by the presence of several breeding sites and frogs appear mobile among these (White and Pyke 1996). Our observations of the Port Kembla population are consistent with this. There are currently six pond sites that are permanently occupied by bell frogs within a radius of 2.5 km. These sites offer a variety of breeding habitats (e.g., ephemeral, permanent, large, small). The importance of this variety is suggested by the moderate breeding that occurred at one site (BHP Steelworks) in a drought year (1998). This also suggests that when translocation is required to establish a population, translocation to a single breeding site may not be effective. The presence of several (4–5) breeding sites within dispersal distance should be viewed as the basis for maintaining a viable population of bell frogs. Based on limited observation, the broad objective for establishing a viable population should be to ensure that the population contains >100 adult frogs. This suggests that intensive management will be required at Bulli and Shellharbour if these sites are to be treated as core populations for regional conservation of the bell frog.

What kind of on-going management is required to establish and maintain a viable population? Various management actions are proposed for the Illawarra sites (Table 2). Generally, we suggest the provision of several fish-free ponds that contain cumbungi or spikerush in which frogs can shelter during the day, in order to offset the loss of breeding sites and invasion by exotic fish. The ponds should not have steep banks but otherwise should follow the guidelines outlined by Pyke and White (1996) such as having a deep and shallow end, and containing clumps of aquatic plants. Where ponds are currently occupied by bell frogs, other small ponds should be provided to safe-guard the main breeding sites from fish colonization and from other catastrophes such as chemical spills. The construction of any new ponds will need to ensure that they fill after heavy rain but without collecting polluted water. Several sites in Port Kembla would benefit in this regard (Table 2). The short-term effectiveness of this strategy has been demonstrated by continued use and successful breeding by bell frogs in the pond at Boilers Point, which was constructed 200 m from an established breeding site where breeding had been extremely poor in the previous two years. Continued monitoring of this pond is required to demonstrate its continued effectiveness.

Water quality is an issue that requires on-going management and research because many sites where bell frogs occur in Port Kembla appear to be polluted. Nutrient levels are known to be high during some periods at some sites (van de Mortel *et al.* 1998). It is not known what the long-term effect of contaminated water will be on frog survival. Some of this contamination would be entering the water bodies in urban runoff, and is exacerbated by the heavy industry in Port Kembla. Thus, drainage patterns should be examined and construction of small wetland filters may be useful in reducing contamination. In some instances the contamination may originate from the pond substrate and may not be easily rectified.

In several cases, existing ponds appear to require modification to improve their suitability for frog breeding (Table 2). For example, the Bellambi Colliery pond is surrounded by trees, has only small areas of typha and has steep banks. These factors may suppress breeding. The alternative of constructing a pond of the type recommended by Pyke and White (1996) could only be achieved at some distance from the site. Existing ponds within a golf course located 1 km away may provide the ideal site for encouraging the multiple breeding sites that appear needed to bolster this population.

A population monitoring programme should be initiated to assess the progress of all management actions and to provide insights into population stability. This should include annual counts of active frogs at many sites using the methods in this study, and permanent tagging at a few sites (Table 2) to provide detailed information (e.g., more precise population counts, data on movement and longevity) that may assist recovery. A detailed study on the dispersal behaviour of juvenile frogs (Table 2) would greatly enhance our understanding of population viability and how it is influenced by multiple breeding sites.

Breeding sites are the focus of management activities. However, some attention must be given to maintaining and enhancing foraging and shelter sites. At Coomaditchy Lagoon for example, mowing patterns by Wollongong City Council had to be modified in order to protect important non-aquatic habitat areas (van de Mortel *et al.* 1998). Public education and direct community involvement are also important issues in the Illawarra because residential areas surround most breeding sites. Community involvement may encourage the development of refuge and minor breeding sites in residential gardens and may help to assess the significance of road mortality. It is recommended that each of the above factors (Table 2) should be included in a conservation strategy in order to achieve recovery of the Green and Golden Bell Frog in the Illawarra region.

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